Predicting the severity of the grass pollen season and the effect of climate change in Northwest Europe

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Supplementary Materials for

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Alexander Kurganskiy*, Simon Creer, Natasha de Vere, Gareth W. Griffith, Nicholas J. Osborne, Benedict W. Wheeler, Rachel N. McInnes, Yolanda Clewlow, Adam Barber, Georgina L. Brennan, Helen M. Hanlon, Matthew Hegarty, Caitlin Potter, Francis Rowney, Beverley Adams-Groom, Geoff M. Petch, Catherine H. Pashley, Jack Satchwell, Letty A. de Weger, Karen Rasmussen, Gilles Oliver, Charlotte Sindt, Nicolas Bruffaerts, The PollerGEN Consortium, Carsten A. Skjøth*

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Supplementary Materials

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Supplementary figures

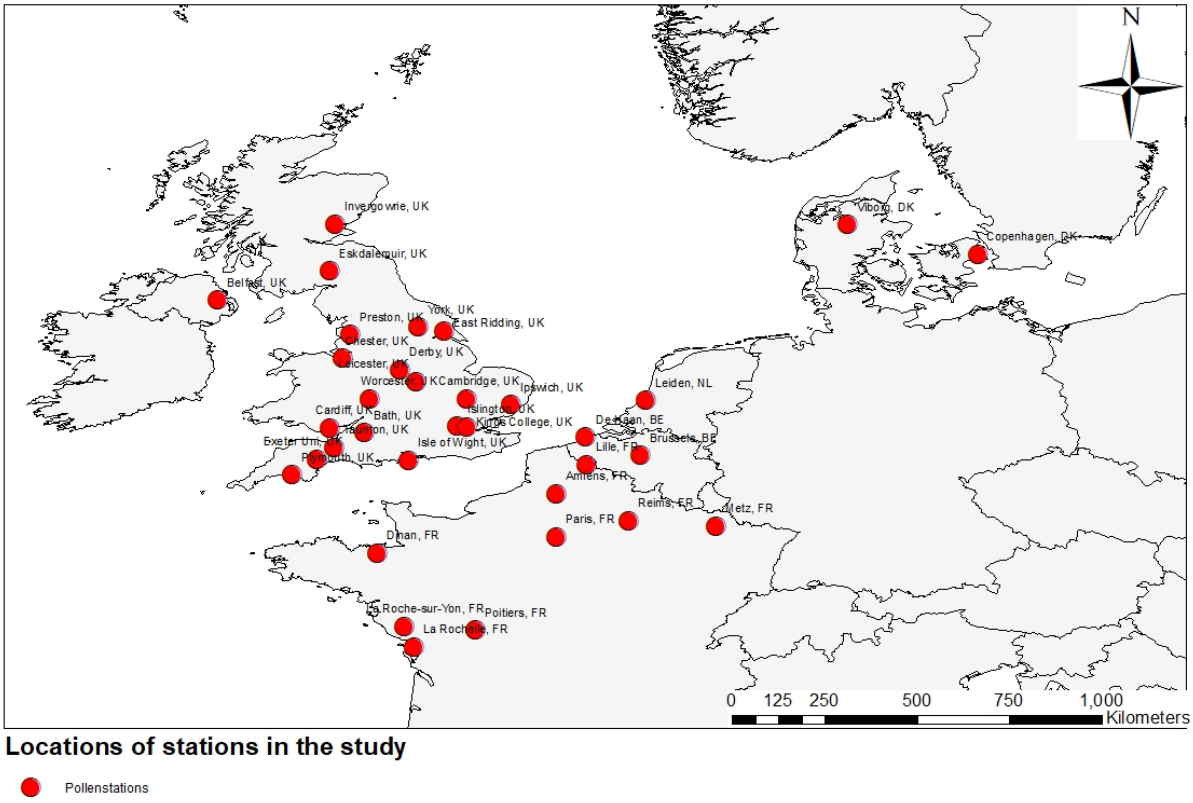

Fig. S1. Geographical distribution of the pollen monitoring stations with corresponding station names utilised in the study.

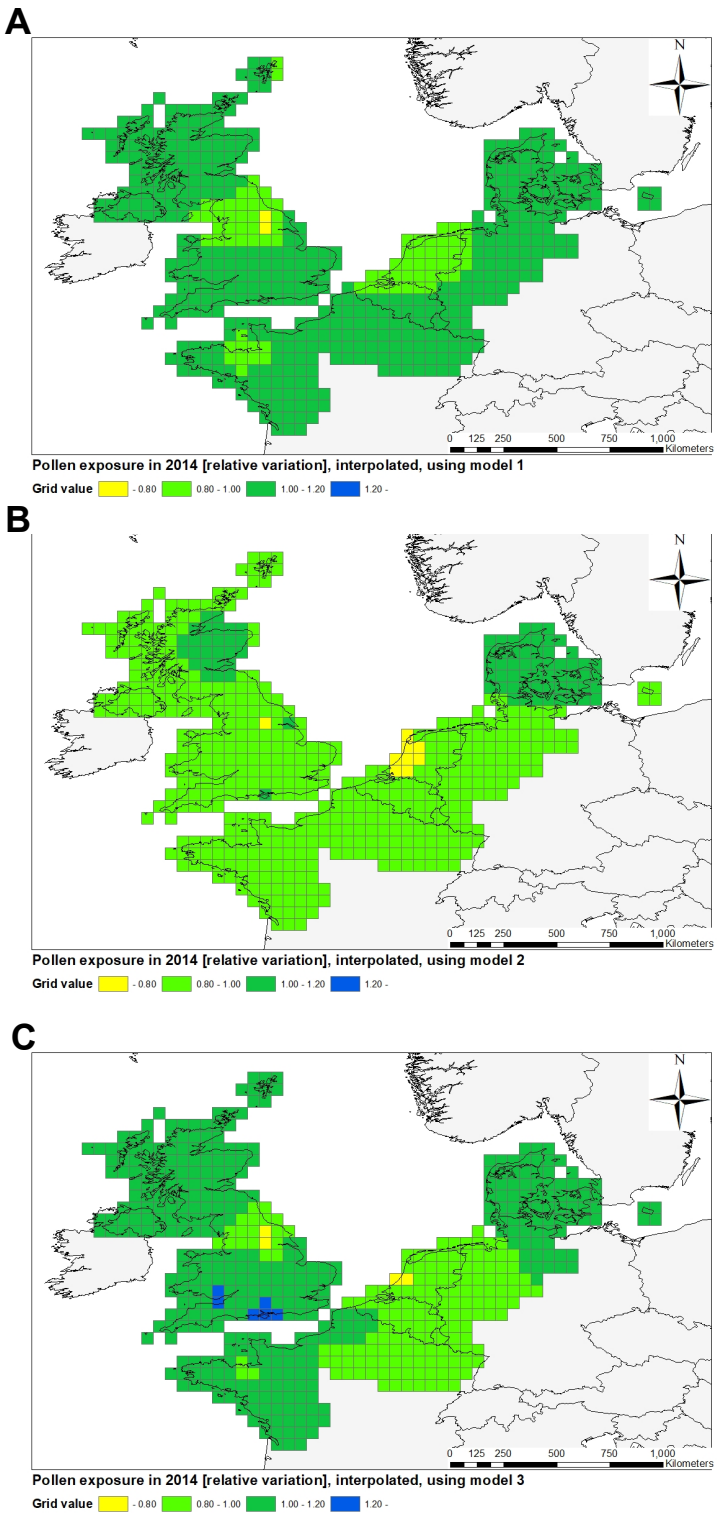

Fig. S2. Map based on interpolating the simulated variation in SPIn using the geospatial regression approach, model 1 (A), model 2 (B) and model 3 (C) for the grass pollen season 2014. The results of model 4 are shown in the manuscript. The variations are calculated relative to the mean SPIn value over the years at each station and interpolated to the grid with 0.5° horizontal resolution.

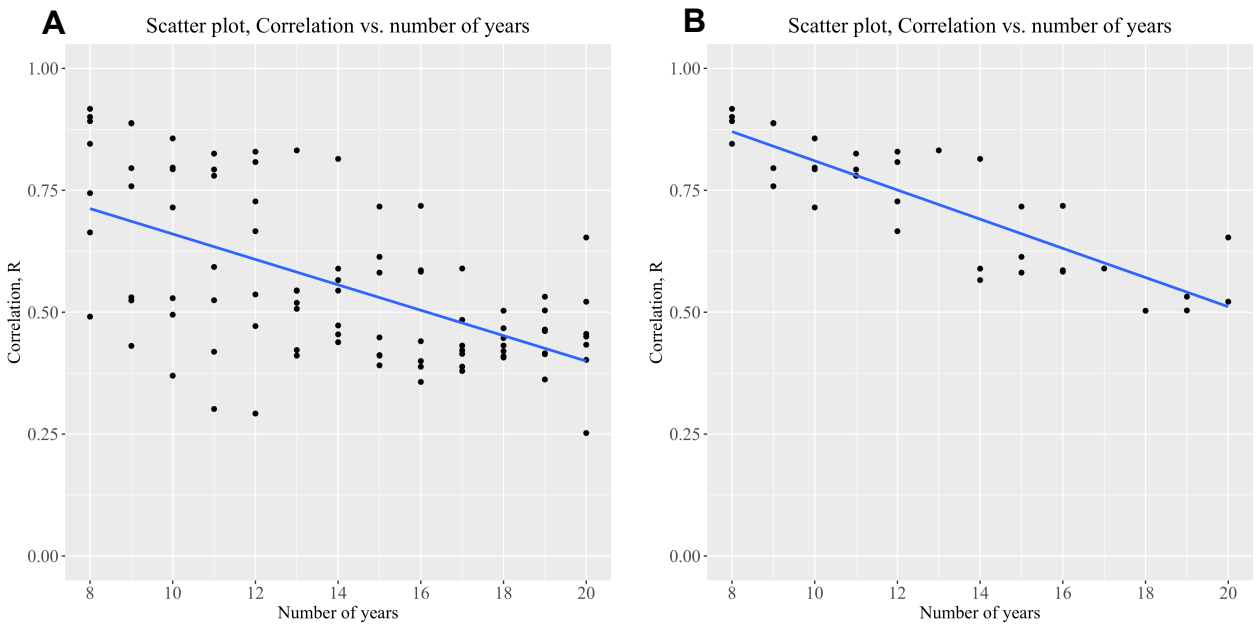

Fig. S3. Distribution of the correlation coefficients depending on the number of years chosen to build the regression model. The data are shown for all values (**A**) and only significant values with P<0.05 (**B**). The results are based on testing Model 4 taking into account SPIn, pre-seasonal air temperature and precipitation. The correlation values have been calculated using the Pearson correlation coefficients for all stations, except 2 values for the station in Worcester (Number of years = 14 and 16) where the Spearman correlation coefficients have been calculated instead.

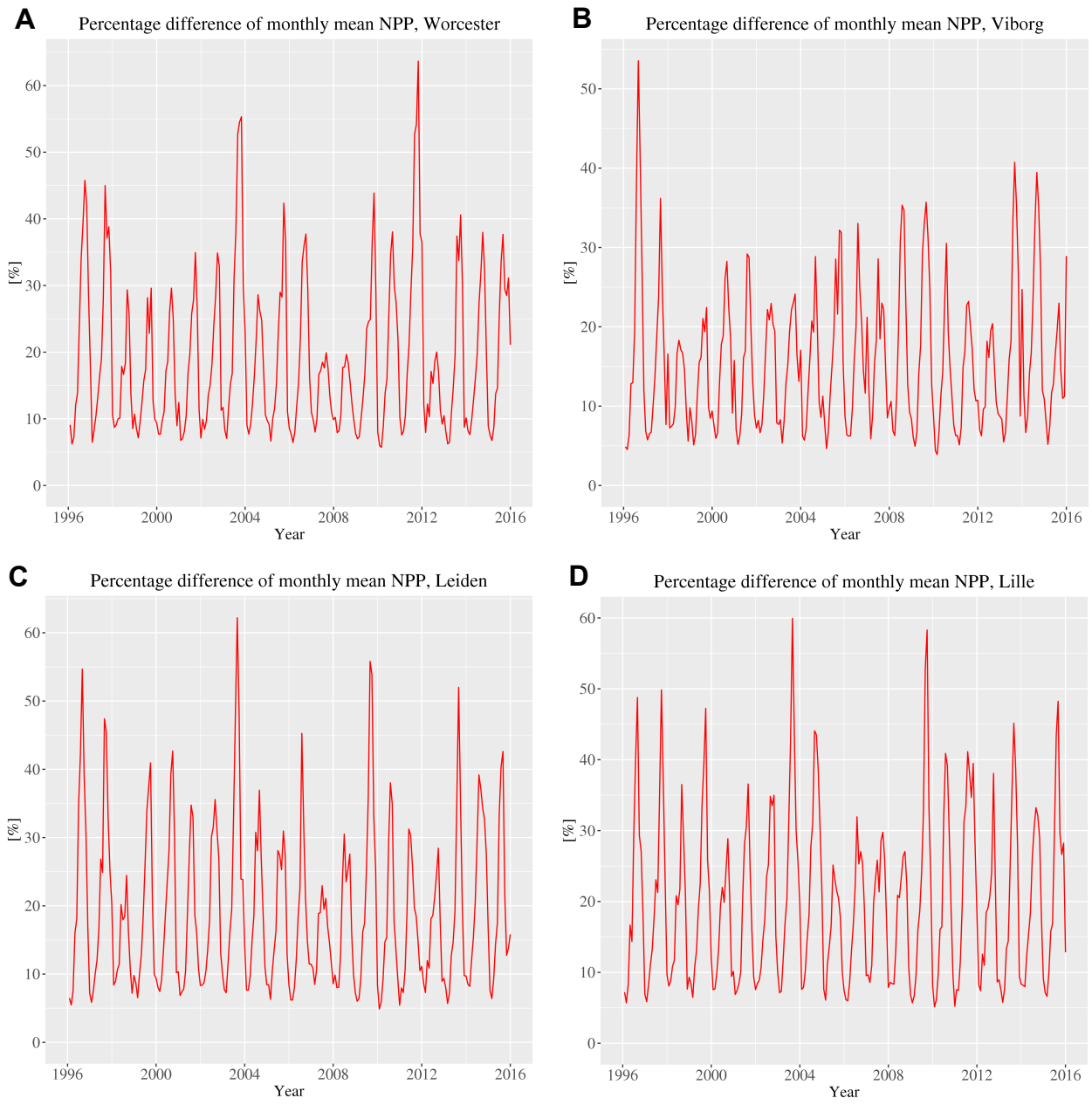

Fig. S4. Percentage difference of monthly mean NPP (doubled CO_2 - default) simulated by JULES.

Table S1. Results of the regression model 1 performance at the selected stations located in Northwest Europe. The regression model is based on Model 1, i.e. including SPIn data only. R denotes correlation coefficient between modelled and observed SPIn with corresponding p-value (P); a,b,c,d – regression coefficients obtained by the non-linear least squares fitting, rm – the maximum production rate observed (the maximum ratio of SPIn calculated relative the mean SPIn over the selected years at each station); N – the total number of years (grass pollen seasons) used at each station. The R values have been calculated using the Pearson correlation coefficients for all stations, except the values in bold where the Spearman correlation coefficients have been calculated instead.

Station	R	P	a	b	c	d	rm	start year	end year	N
Worcester	0.27	0.2221	0.3431	-2.2511	NA	NA	1.9755	1996	2018	23
Plymouth	0.21	0.3813	0.383	-2.3948	NA	NA	1.8388	1996	2015	20
Cardiff	0.02	0.9562	0.6068	-4.5575	NA	NA	1.3796	2006	2018	13
Isle of Wight	0.42	0.1531	0.3628	-2.5259	NA	NA	1.6091	2005	2018	14
Leicester	0.29	0.2286	0.5949	-4.6405	NA	NA	1.382	1999	2018	20
Belfast	0.52	0.0675	0.235	-1.3539	NA	NA	1.7453	1996	2009	14
York	0.67	0.0331	0.1799	-0.9404	NA	NA	1.8339	2008	2018	11
Preston	0.40	0.1745	0.4377	-3.386	NA	NA	1.4511	1996	2009	14
Cambridge	0.41	0.0937	0.4261	-3.1111	NA	NA	1.4564	1996	2014	19
Islington	0.09	0.8463	0.8923	-7.2903	NA	NA	1.1832	2002	2009	8
Invergowrie	-0.13	0.7856	0.4277	-2.5782	NA	NA	1.8125	2011	2018	8
Ipswich	0.69	0.0835	0.4803	-3.5754	NA	NA	1.4548	2011	2018	8
East Riding	-0.29	0.5560	0.6693	-4.7162	NA	NA	1.647	2011	2018	8
Derby	0.39	0.3011	0.3979	-3.0801	NA	NA	1.5199	1996	2005	10
Leiden	0.68	5e-04	0.156	-0.4838	NA	NA	2.1702	1996	2018	23
Brussels	0.02	0.9264	0.798	-5.9722	NA	NA	1.3469	1996	2018	23
De Haan	0.47	0.028	0.2905	-1.4533	NA	NA	1.8956	1996	2018	23
Copenhagen	0.41	0.0589	0.4407	-3.0082	NA	NA	1.522	1996	2018	23
Viborg	0.50	0.0179	0.3432	-2.1712	NA	NA	1.6297	1996	2018	23
Lille	0.48	0.2247	0.5066	-3.7534	NA	NA	1.4193	2010	2018	9
Paris	0.23	0.5798	0.6538	-4.9239	NA	NA	1.2938	2010	2018	9
Poitiers	0.66	0.0736	0.298	-2.1732	NA	NA	1.3618	2010	2018	9
Dinan	0.48	0.2244	1.3228	-10.5872	NA	NA	1.3487	2010	2018	9
La Roche-sur-Yon	0.39	0.3431	0.4426	-3.4252	NA	NA	1.471	2010	2018	9
Amiens	0.29	0.4809	0.6591	-5.1166	NA	NA	1.2843	2010	2018	9
Reims	0.30	0.4656	1.0656	-7.9956	NA	NA	1.482	2010	2018	9
Metz	0.24	0.5736	1.1859	-8.8026	NA	NA	1.5752	2010	2018	9
La Rochelle	0.08	0.8493	0.6054	-4.6577	NA	NA	1.3261	2010	2018	9

Table S2. Results of the regression model 2 performance at the selected stations located in Northwest Europe. The regression model is based on Model 2, i.e. including the SPIn and Tmax data. R denotes correlation coefficient between modelled and observed SPIn with corresponding p-value (P); a,b,c,d – regression coefficients obtained by the non-linear least squares fitting, rm – the maximum production rate observed (the maximum ratio of SPIn calculated relative the mean SPIn over the selected years at each station); N – the total number of years (grass pollen seasons) used at each station. The R values have been calculated using the Pearson correlation coefficients for all stations, except the values in bold where the Spearman correlation coefficients have been calculated instead.

Station	R	P	a	b	c	d	rm	start year	end year	N
Worcester	0.46	0.0322	0.29	-3.3953	0.6296	NA	1.9755	1996	2018	23
Plymouth	0.61	0.0052	0.3665	-4.5736	0.9303	NA	1.8388	1996	2015	20
Cardiff	0.56	0.0584	0.5677	-6.6199	0.9723	NA	1.3796	2006	2018	13
Isle of Wight	0.74	0.004	0.2922	-3.7366	0.7562	NA	1.6091	2005	2018	14
Leicester	0.51	0.0263	0.609	-6.6269	0.7577	NA	1.382	1999	2018	20
Belfast	0.54	0.0592	0.2112	-2.387	0.512	NA	1.7453	1996	2009	14
York	0.70	0.0252	0.1054	1.15	-0.5951	NA	1.8339	2008	2018	11
Preston	0.46	0.1186	0.4277	-4.0097	0.2928	NA	1.4511	1996	2009	14
Cambridge	0.76	3e-04	0.3825	-5.2974	1.0167	NA	1.4564	1996	2014	19
Islington	0.48	0.2786	0.6637	-7.2763	0.7363	NA	1.1832	2002	2009	8
Invergowrie	0.58	0.1753	0.2504	-3.2582	0.86	NA	1.8125	2011	2018	8
Ipswich	0.82	0.0243	0.4062	-4.2004	0.5041	NA	1.4548	2011	2018	8
East Riding	-0.14	0.7825	0.6715	-4.8723	0.0606	NA	1.647	2011	2018	8
Derby	0.54	0.1338	0.3568	-5.6747	1.192	NA	1.5199	1996	2005	10
Leiden	0.68	5e-04	0.1687	-1.2092	0.2499	NA	2.1702	1996	2018	23
Brussels	0.20	0.3754	0.8487	-7.0969	0.2866	NA	1.3469	1996	2018	23
De Haan	0.45	0.0337	0.2859	-1.9755	0.2277	NA	1.8956	1996	2018	23
Copenhagen	0.41	0.0589	0.4407	-3.0051	-0.0013	NA	1.522	1996	2018	23
Viborg	0.53	0.0109	0.3442	-1.9135	-0.1183	NA	1.6297	1996	2018	23
Lille	0.80	0.0184	0.5318	-6.2425	0.8817	NA	1.4193	2010	2018	9
Paris	0.80	0.0167	0.7827	-8.2257	0.8517	NA	1.2938	2010	2018	9
Poitiers	0.93	7e-04	0.3228	-5.9732	1.3185	NA	1.3618	2010	2018	9
Dinan	0.65	0.0808	1.3609	-13.0719	0.8356	NA	1.3487	2010	2018	9
La Roche-sur-Yon	0.68	0.0644	0.4516	-8.6993	1.9269	NA	1.471	2010	2018	9
Amiens	0.28	0.503	0.7029	-5.7472	0.1087	NA	1.2843	2010	2018	9
Reims	0.37	0.365	1.0993	-9.3766	0.4242	NA	1.482	2010	2018	9
Metz	0.52	0.1899	1.4271	-14.6005	1.4975	NA	1.5752	2010	2018	9
La Rochelle	0.71	0.048	0.486	-8.5122	1.7772	NA	1.3261	2010	2018	9

Table S3. Results of the regression model 3 performance at the selected stations located in Northwest Europe. The regression model is based on Model 3, i.e. including the SPIn and Nprec data. R denotes correlation coefficient between modelled and observed SPIn with corresponding p-value (P); a,b,c,d – regression coefficients obtained by the non-linear least squares fitting, rm – the maximum production rate observed (the maximum ratio of SPIn calculated relative the mean SPIn over the selected years at each station); N – the total number of years (grass pollen seasons) used at each station. The R values have been calculated using the Pearson correlation coefficients for all stations.

Station	R	P	a	b	c	d	rm	start year	end year	N
Worcester	0.48	0.0248	0.2891	-0.9425	NA	-0.2601	1.9755	1996	2018	23
Plymouth	0.29	0.2297	0.3907	-2.1568	NA	-0.0898	1.8388	1996	2015	20
Cardiff	0.78	0.0029	0.5742	-3.0669	NA	-0.3825	1.3796	2006	2018	13
Isle of Wight	0.51	0.0746	0.3463	-1.7967	NA	-0.1809	1.6091	2005	2018	14
Leicester	0.32	0.1836	0.6398	-4.5633	NA	-0.1405	1.382	1999	2018	20
Belfast	0.62	0.0234	0.1428	0.3465	NA	-0.2683	1.7453	1996	2009	14
York	0.71	0.0216	0.1339	-1.0557	NA	0.1594	1.8339	2008	2018	11
Preston	0.40	0.1755	0.4294	-3.1968	NA	-0.0349	1.4511	1996	2009	14
Cambridge	0.75	4e-04	0.4656	-2.6204	NA	-0.2656	1.4564	1996	2014	19
Islington	0.08	0.8713	0.8678	-7.0293	NA	-0.0175	1.1832	2002	2009	8
Invergowrie	0.30	0.5122	0.4549	-1.0635	NA	-0.5154	1.8125	2011	2018	8
Ipswich	0.81	0.0267	0.4661	-2.8287	NA	-0.1869	1.4548	2011	2018	8
East Riding	0.48	0.2748	0.5968	-4.6953	NA	0.1581	1.647	2011	2018	8
Derby	0.67	0.0486	0.2757	-0.5	NA	-0.4716	1.5199	1996	2005	10
Leiden	0.71	2e-04	0.2134	-0.5803	NA	-0.114	2.1702	1996	2018	23
Brussels	0.20	0.3855	0.8853	-6.383	NA	-0.0851	1.3469	1996	2018	23
De Haan	0.48	0.0233	0.2975	-1.3054	NA	-0.0635	1.8956	1996	2018	23
Copenhagen	0.62	0.0022	0.4467	-2.3809	NA	-0.2321	1.522	1996	2018	23
Viborg	0.50	0.0187	0.3484	-2.112	NA	-0.0315	1.6297	1996	2018	23
Lille	0.49	0.2155	0.5508	-3.6534	NA	-0.1409	1.4193	2010	2018	9
Paris	0.55	0.161	0.842	-5.6873	NA	-0.2362	1.2938	2010	2018	9
Poitiers	0.67	0.0713	0.3627	-2.377	NA	-0.1042	1.3618	2010	2018	9
Dinan	0.83	0.0112	1.0351	-7.0843	NA	-0.3536	1.3487	2010	2018	9
La Roche-sur-Yon	0.63	0.0968	0.4205	-2.1619	NA	-0.338	1.471	2010	2018	9
Amiens	0.31	0.4522	0.6517	-5.1787	NA	0.0364	1.2843	2010	2018	9
Reims	0.31	0.4548	1.1157	-8.64	NA	0.079	1.482	2010	2018	9
Metz	0.54	0.1706	1.3328	-8.4618	NA	-0.5195	1.5752	2010	2018	9
La Rochelle	0.09	0.824	0.6062	-4.4959	NA	-0.0507	1.3261	2010	2018	9

Table S4. Results of the regression model 4 performance at the selected stations located in Northwest Europe. The regression model is based on Model 4, i.e. including the SPIn, Tmax and Nprec data. R denotes correlation coefficient between modelled and observed SPIn with corresponding p-value (P); a,b,c,d – regression coefficients obtained by the non-linear least squares fitting, rm – the maximum production rate observed (the maximum ratio of SPIn calculated relative the mean SPIn over the selected years at each station); N – the total number of years (grass pollen seasons) used at each station. The R values have been calculated using the Pearson correlation coefficients for all stations.

Station	R	P	a	b	c	d	rm	start year	end year	N
Worcester	0.51	0.0154	0.2777	-1.665	0.255	-0.2069	1.9755	1996	2018	23
Plymouth	0.61	0.0051	0.3645	-4.6596	0.9531	0.0136	1.8388	1996	2015	20
Cardiff	0.82	0.0011	0.5803	-4.3512	0.4141	-0.3131	1.3796	2006	2018	13
Isle of Wight	0.74	0.0039	0.2934	-3.6363	0.7326	-0.0168	1.6091	2005	2018	14
Leicester	0.52	0.022	0.6236	-6.4362	0.6917	-0.0465	1.382	1999	2018	20
Belfast	0.64	0.0188	0.1392	0.985	-0.1914	-0.311	1.7453	1996	2009	14
York	0.71	0.0211	0.0893	0.7654	-0.5037	0.0936	1.8339	2008	2018	11
Preston	0.49	0.0917	0.4441	-4.9084	0.4827	0.0883	1.4511	1996	2009	14
Cambridge	0.82	2.8e-5	0.4249	-4.1471	0.6154	-0.1606	1.4564	1996	2014	19
Islington	0.72	0.0656	1.0561	-14.5814	1.7152	0.472	1.1832	2002	2009	8
Invergowrie	0.57	0.1779	0.2771	-2.8196	0.7671	-0.1264	1.8125	2011	2018	8
Ipswich	0.87	0.0116	0.394	-3.4493	0.449	-0.1531	1.4548	2011	2018	8
East Riding	0.49	0.2637	0.5968	-5.0701	0.137	0.1756	1.647	2011	2018	8
Derby	0.69	0.0409	0.2562	3.6114	-1.2153	-0.7612	1.5199	1996	2005	10
Leiden	0.70	3e-04	0.2075	-0.8173	0.0883	-0.0939	2.1702	1996	2018	23
Brussels	0.24	0.2849	0.8922	-7.0435	0.2047	-0.0581	1.3469	1996	2018	23
De Haan	0.47	0.0281	0.2921	-1.7287	0.1651	-0.0444	1.8956	1996	2018	23
Copenhagen	0.63	0.0017	0.446	-2.162	-0.0867	-0.24	1.522	1996	2018	23
Viborg	0.53	0.011	0.3524	-1.7928	-0.1323	-0.0485	1.6297	1996	2018	23
Lille	0.80	0.0182	0.5459	-6.1457	0.8589	-0.0469	1.4193	2010	2018	9
Paris	0.83	0.0113	0.8357	-7.9811	0.7251	-0.1057	1.2938	2010	2018	9
Poitiers	0.94	5e-04	0.2864	-6.0843	1.4069	0.0541	1.3618	2010	2018	9
Dinan	0.83	0.0111	1.0604	-7.7813	0.1454	-0.3189	1.3487	2010	2018	9
La Roche-sur-Yon	0.79	0.0204	0.442	-7.0611	1.7021	-0.2989	1.471	2010	2018	9
Amiens	0.29	0.4823	0.6946	-5.7423	0.1009	0.0245	1.2843	2010	2018	9
Reims	0.38	0.349	1.2414	-11.3096	0.4794	0.2108	1.482	2010	2018	9
Metz	0.61	0.107	1.3759	-11.3729	0.7955	-0.3441	1.5752	2010	2018	9
La Rochelle	0.72	0.0463	0.4574	-9.8386	2.123	0.1867	1.3261	2010	2018	9

Table S5. Results of the mechanistic model performance at the selected stations located in Northwest Europe. R denotes correlation coefficient between interannual variations of modelled NPP and observed SPIn with corresponding p-value (P); N – the total number of years (grass pollen seasons) used at each station. The R values have been calculated using the Pearson correlation coefficients for all stations, except the values in bold where the Spearman correlation coefficients have been calculated instead.

Station	R	P	N
Worcester	0.506	0.0193	21
Plymouth	0.17	0.473	20
Cardiff	0.162	0.507	19
Isle of Wight	-0.00624	0.982	15
Leicester	0.469	0.0384	20
Belfast	0.388	0.0911	20
York	0.549	0.126	9
Preston	0.426	0.129	14
Cambridge	0.542	0.0165	19
Islington	0.462	0.115	13
Invergowrie	0.255	0.359	15
Ipswich	0.939	0.00555	6
East Ridding	0.655	0.158	6
Derby	0.69	0.0272	10
Leiden	-0.309	0.173	21
Brussels	-0.0682	0.769	21
De Haan	0.403	0.0702	21
Copenhagen	0.00722	0.975	21
Viborg	-0.269	0.239	21
Lille	0.233	0.615	7
Paris	0.101	0.829	7
Poitiers	0.166	0.723	7
Dinan	0.558	0.193	7
La Roche-sur-Yon	0.615	0.142	7
Amiens	0.301	0.511	7
Reims	-0.00959	0.984	7
Metz	-0.606	0.149	7
La Rochelle	0.000	1.000	7
Kings College	-0.359	0.552	5
Eskdalemuir	0.291	0.576	6
Taunton	-0.49	0.217	8
Bath	0.175	0.74	6
Chester	-0.0342	0.966	4
Exeter	0.996	0.0576	3

Table S6. Results of the observed SPIn time series analysis covering all available years and stations. SPIn Mean, SPIn Median and SPIn SD are the mean, median and standard deviation of the observed SPIn at each station; W – the result of the Shapiro-Wilk normality test with corresponding p-value (P); N – the total number of years (grass pollen seasons) available at each station in the study.

Station	SPIn Mean	SPIn Median	SPIn SD	W	P	N
Worcester	5238	4969	1847	0.903	0.0292	23
Plymouth	2802	2774	982	0.9667	0.6359	22
Cardiff	3190	3182	855	0.9751	0.8418	21
Isle of Wight	4282	3903	1488	0.958	0.5935	17
Leicester	4220	4332	1041	0.9617	0.5245	22
Belfast	3248	3018	1129	0.9154	0.061	22
York	5658	4793	2920	0.9259	0.3706	11
Preston	5271	5592	1294	0.9602	0.7264	14
Cambridge	3717	3911	946	0.9448	0.3215	19
Islington	3778	4128	1054	0.9271	0.3123	13
Invergowrie	1913	1734	734	0.8834	0.0361	17
Ipswich	3246	3382	1054	0.9524	0.7354	8
East Ridding	2114	2170	824	0.9539	0.7505	8
Derby	6077	6160	1947	0.9904	0.9973	10
Leiden	3500	3230	1411	0.9072	0.0356	23
Brussels	2574	2559	531	0.9329	0.1263	23
De Haan	1403	1336	645	0.9535	0.345	23
Copenhagen	2327	2334	566	0.9846	0.9674	23
Viborg	2234	2250	728	0.9614	0.4915	23
Lille	3006	3163	972	0.9471	0.6579	9
Paris	2664	2669	502	0.9587	0.7849	9
Poitiers	3743	3960	986	0.9131	0.3381	9
Dinan	3853	3680	837	0.966	0.859	9
La Roche-sur-Yon	5215	5328	1571	0.9635	0.8341	9
Amiens	3323	3471	707	0.9041	0.2769	9
Reims	2694	2574	794	0.9915	0.9978	9
Metz	2314	2214	929	0.9543	0.7374	9
La Rochelle	3500	3452	990	0.94	0.5814	9
Kings College	2674	2540	748	0.9443	0.6943	6
Eskdalemuir	2518	2561	606	0.9901	0.9934	7
Taunton	2826	2806	832	0.9487	0.6985	8
Bath	1491	1442	430	0.8939	0.3389	6
Chester	6942	6992	921	0.9621	0.8354	6
Exeter	4456	3372	2868	0.8755	0.2896	5

Data file S1. Data used to produce all figures (Fig. 1 – Fig. 5, Fig. S1 – Fig. S4) in the study.
The data are in one Excel file with a number of sheets named “Fig1”, “Fig2a”, “Fig2b”, etc.